Diffusion Issues of Heat and Light Species in Laser Fusion Devices

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  - Issues in structural and coolant
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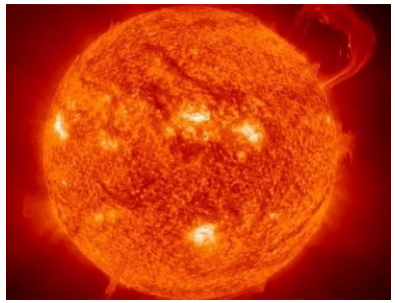
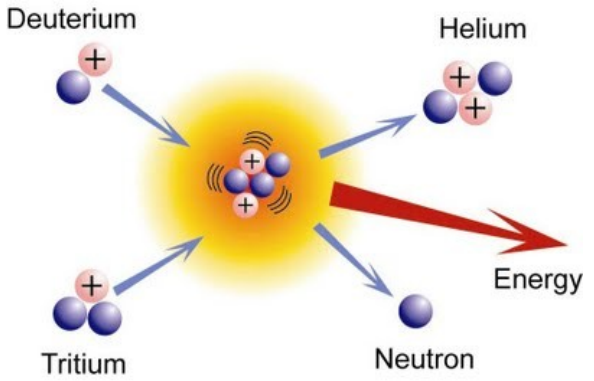
  - Another issues: vacuum chamber, thermodynamical cycle...
- Conclusions

Brief introduction to Nuclear Fusion



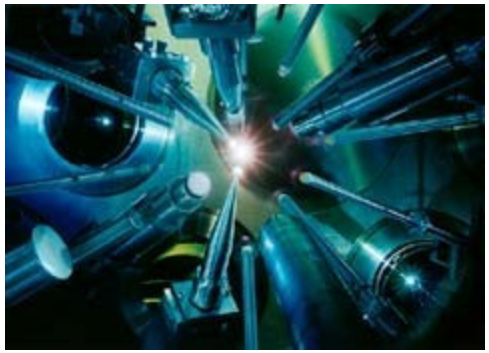
Nuclear Fusion



Extremal conditions
- High temperature
- High confinement

Inertial confinement

Laser drive

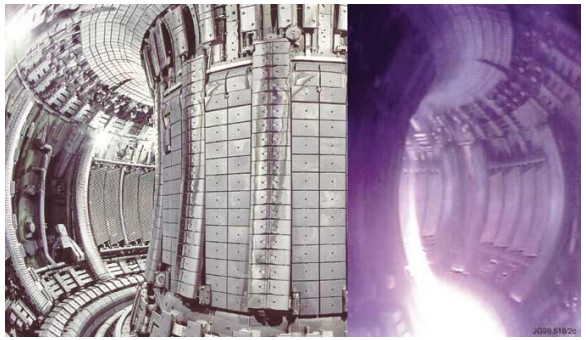


NIF chamber
Livermore, USA

Magnetic confinement

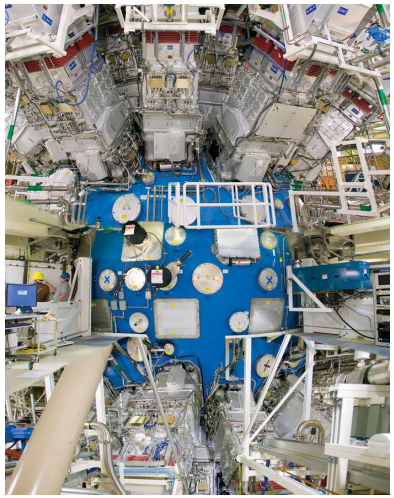
Tokamak, stellarators

JET tokamak
Oxfordshire, UK



Nuclear fusion: Current status

Inertial confinement



NIF chamber
Livermore, USA

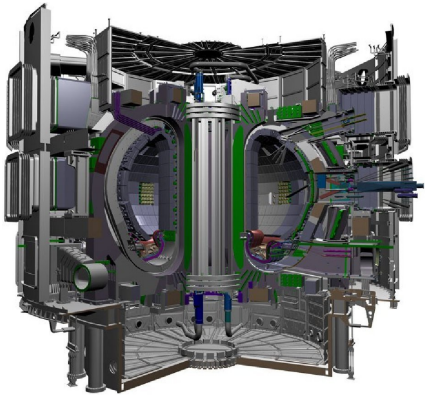
Demonstration of fusion ignition by the end 2012

Demonstrator
GAIN > 1

Commercial Reactor

Magnetic confinement

ITER design



Under construction in Cadarache, France. Programmed ignition in 2026.

LIFE HiPER **LIFT**

DEMO
DEMOnstration power plant 2-4 GW

HiPER project

HiPER

October 2006

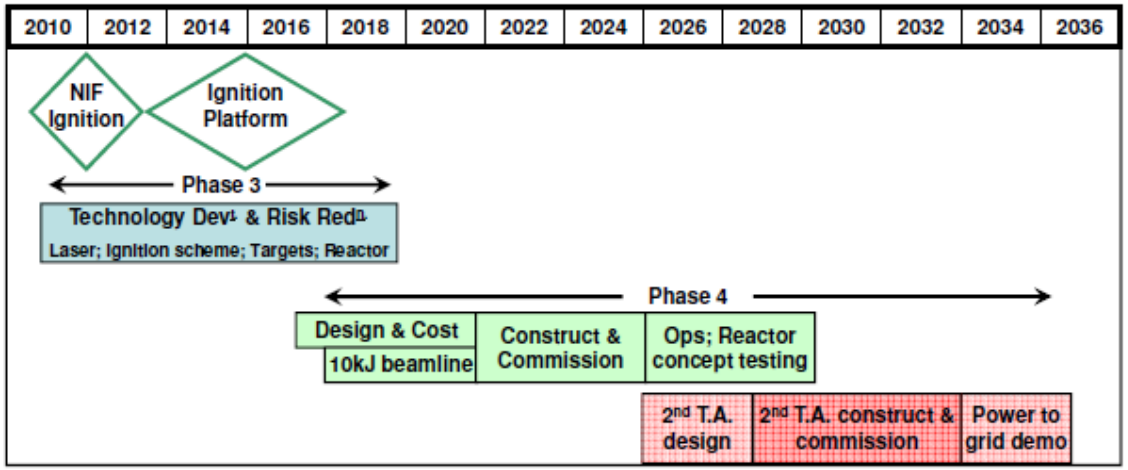
European Strategy Forum on Research Infrastructures

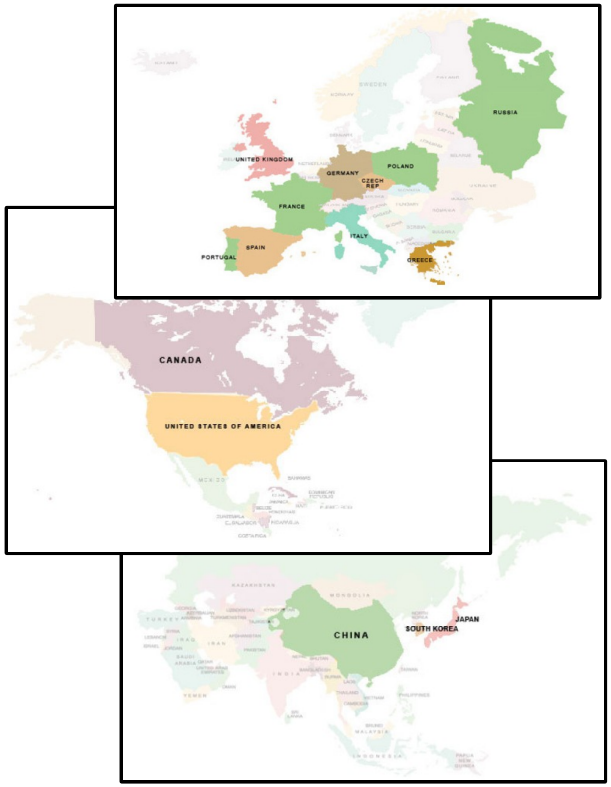
ESFRI

- Single major facility construction step to deliver laser energy

Now → HiPER → Roll-out

- Exploit systems separability to accelerate delivery





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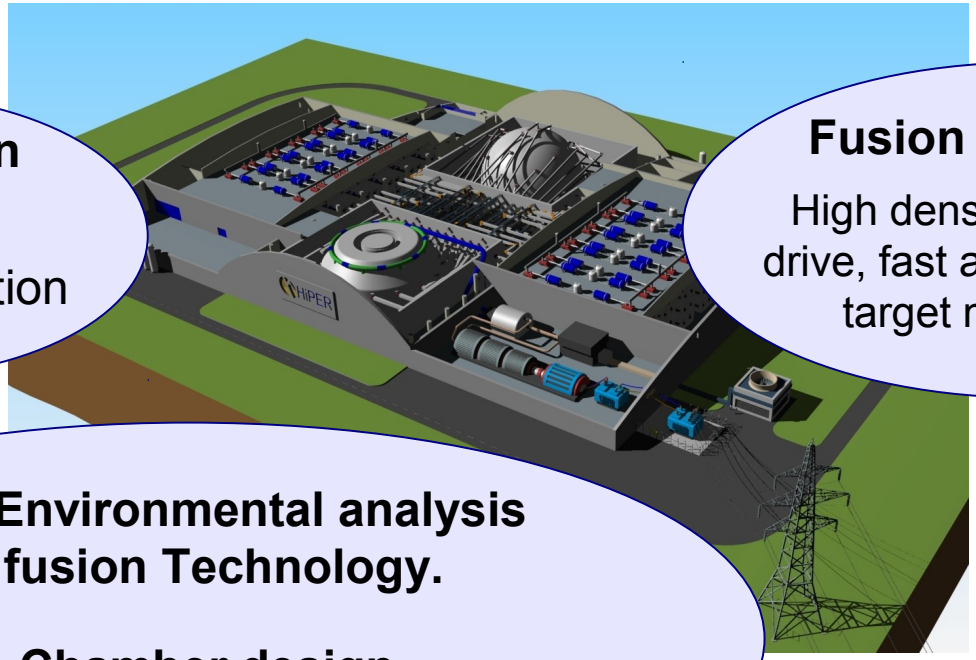
HiPER tasks



Facility design and costing

Systems integration

Fusion target design

High density matter, direct drive, fast and shock ignition, target manufacturing

Safety, Environmental analysis and fusion Technology.

Chamber design

Materials R&D

Heat and mass diffusion simulations

Blankets

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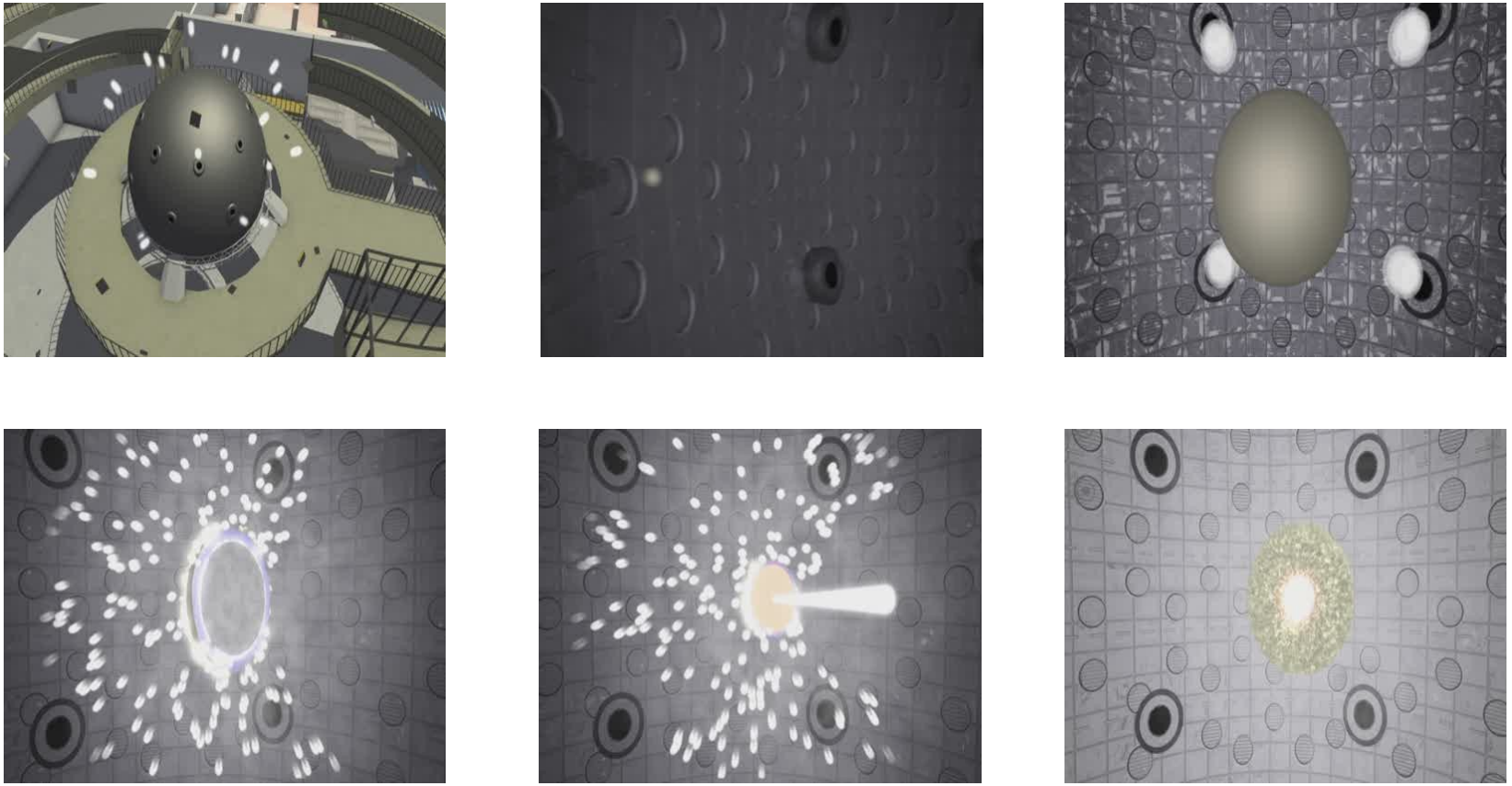
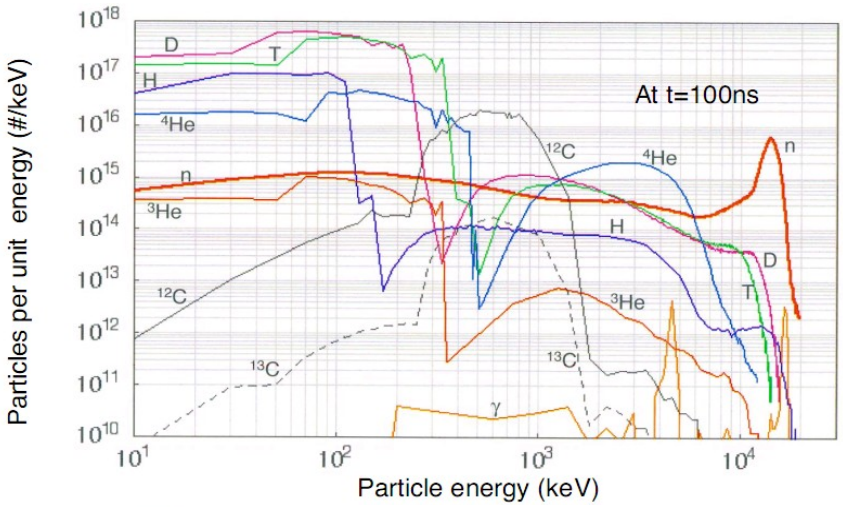
Inertial Fusion Confinement IFC

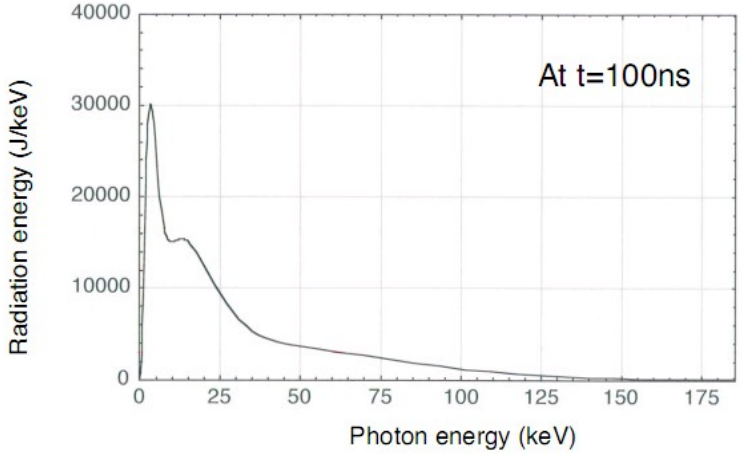


HiPER fast ignition scheme

Energy distribution of fusion products

Perkins spectra 100 ps simulation



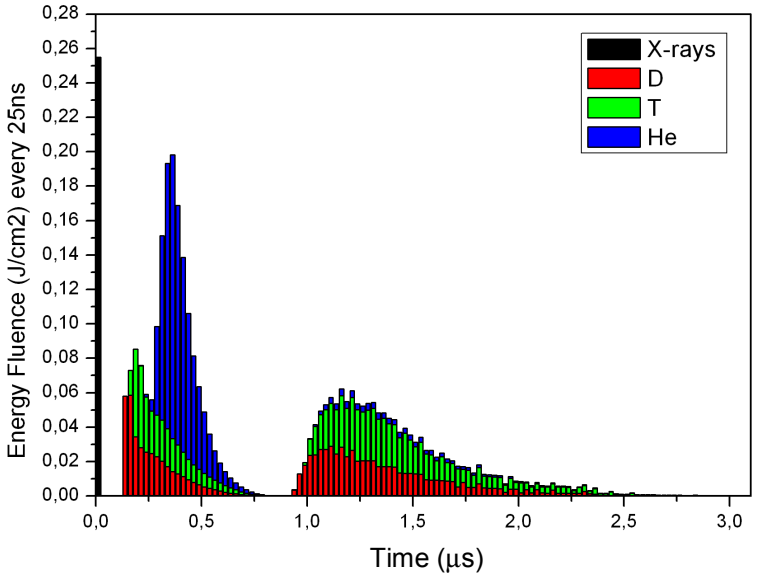


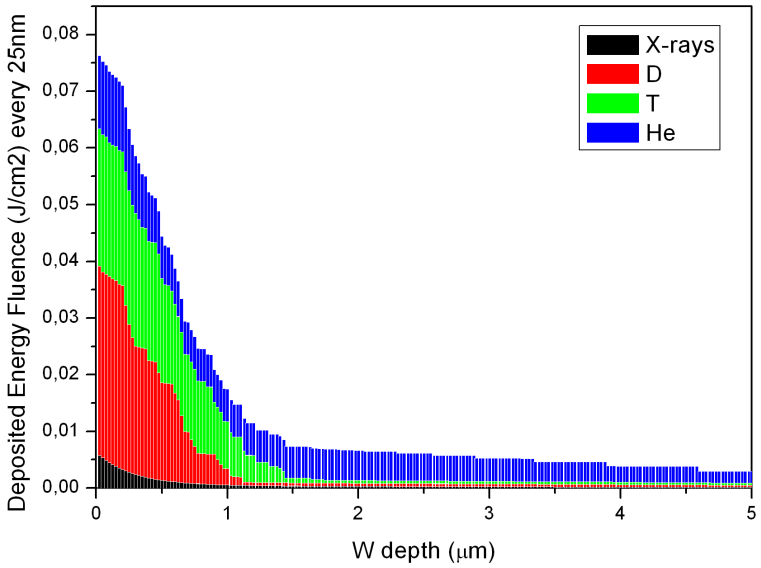
Distribution of 48 MJ shock ignition target

Species	Energy (J)	%
X-rays	6.5×10^5	1.42
Neutrons	3.6×10^7	75.03
Deuterons	2.9×10^6	6.04
Tritons	3.5×10^6	7.29
He	3.6×10^6	7.5
C	1×10^6	2.08
Gamma rays, H, 3He, 13C	3×10^5	0.63

Energy deposition

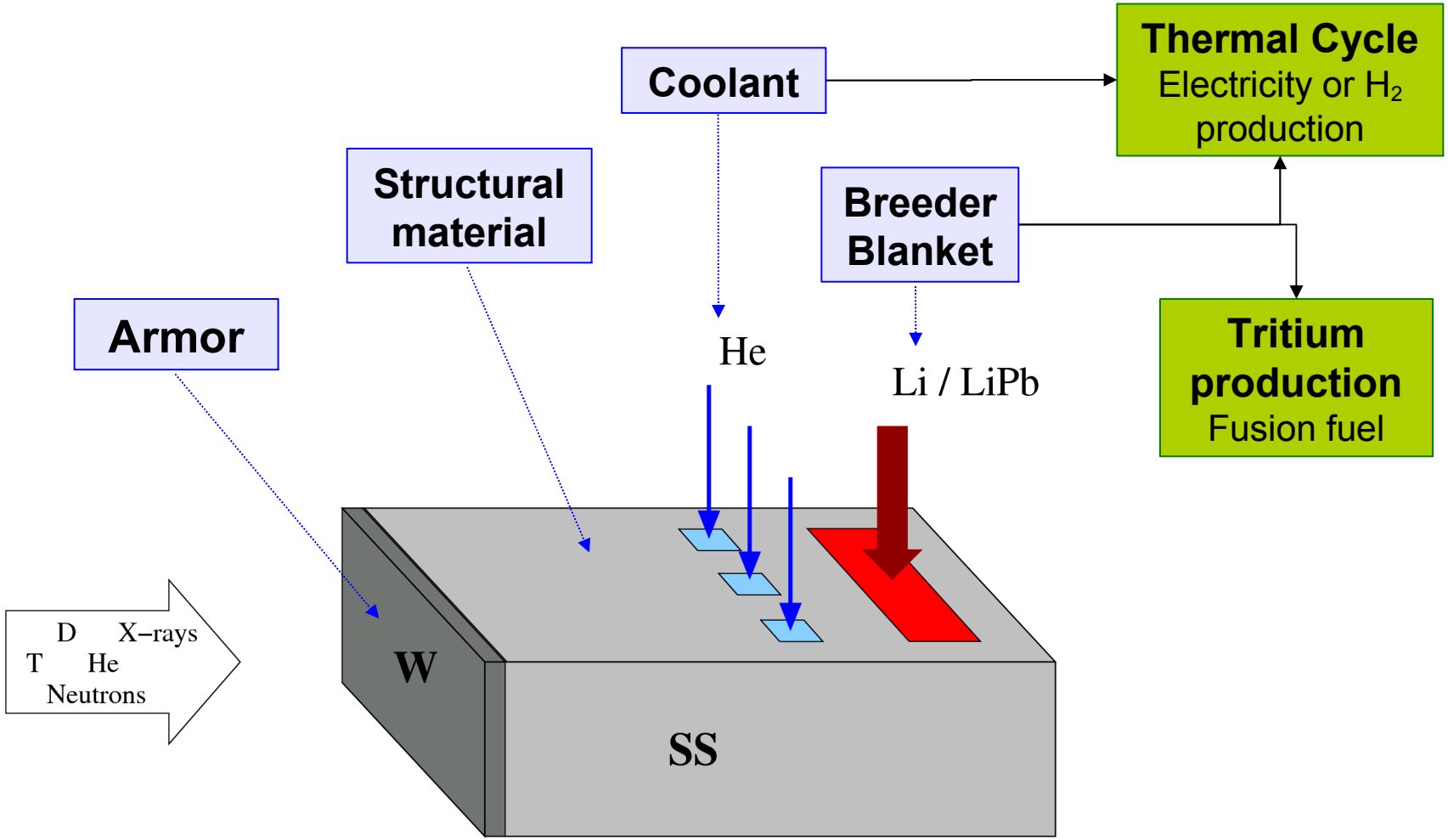
X-rays and ions (deuterons D, tritons T and Helium He are deposited in the first microns of the chamber wall. Temporal and spatial deposition have been calculated for a tungsten armor at 5 meters (*Alvarez 2011*).





Neutrons (75 % of the energy) show almost no interaction with the metallic wall. Mostly stopped in the blanket.

IFC chamber design

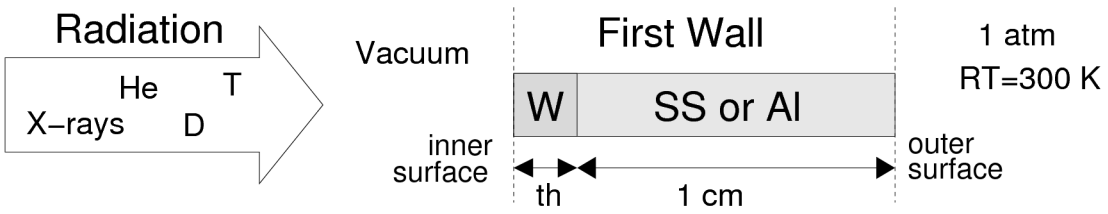


Heat and mass diffusion problems

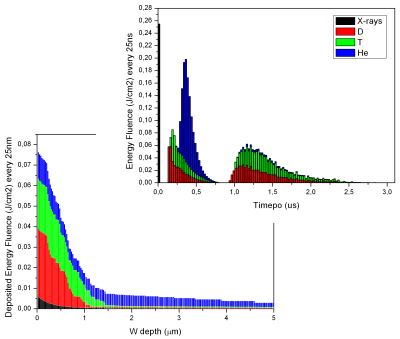
- Diffusion into metals (armor or structural material)
  - Pure metals or alloys
  - ODS and nano-structured materials
  - Metals with atomistic defects (vacancies, interstitial, bubbles...)
- Diffusion in liquids or gas.
  - Liquid metal breeder blanket (Li or LiPb)
  - Coolant (He)
  - Vacuum chamber and pumps
- Diffusion between two media
  - Armor and structural with or with out interlayer
  - Vacuum chamber and armor
  - Structural and coolant (He)
  - Structural and blanket (Li or LiPb) with interlayer (SiC or W)

Issues in first wall: temperature

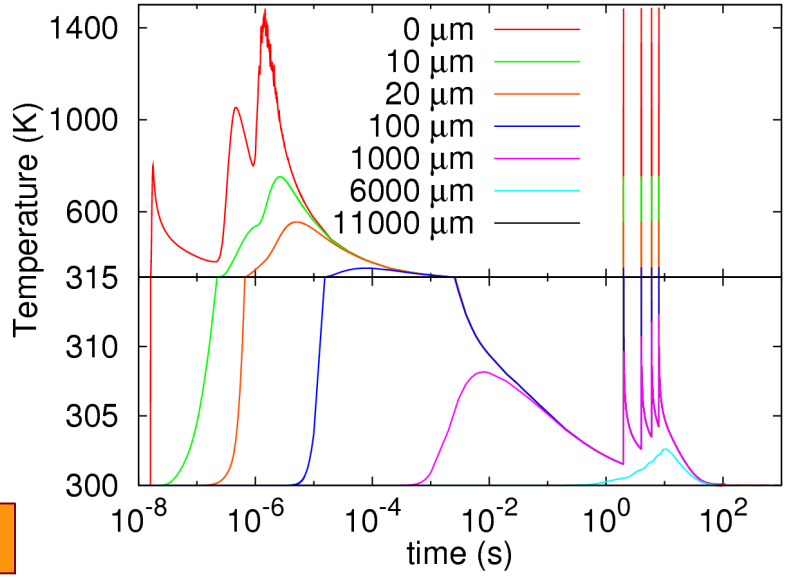
Finite element solver ASTER CODE is used to estimate thermo-mechanical behavior in the first wall (temperature, stress, deformation)



Energy deposition



Bunch of 5 shock ignitions
48 MJ in 10 seconds
(scenario HiPER 4a)

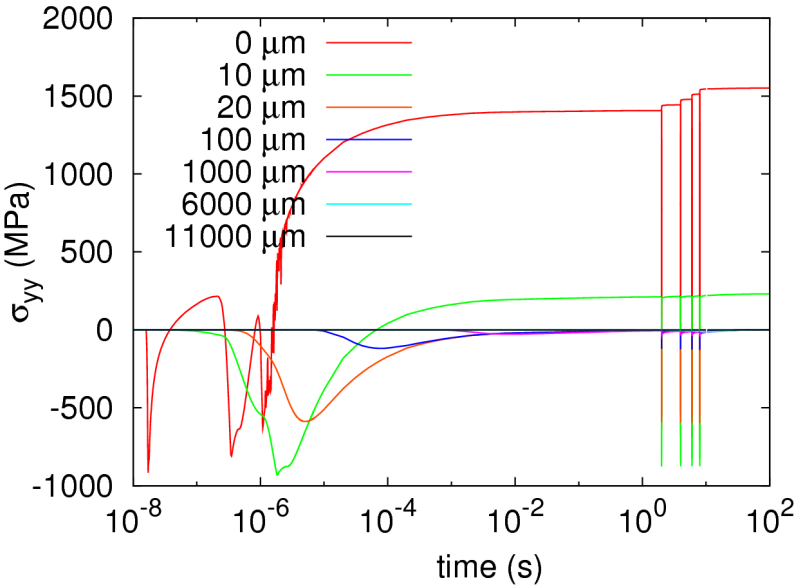


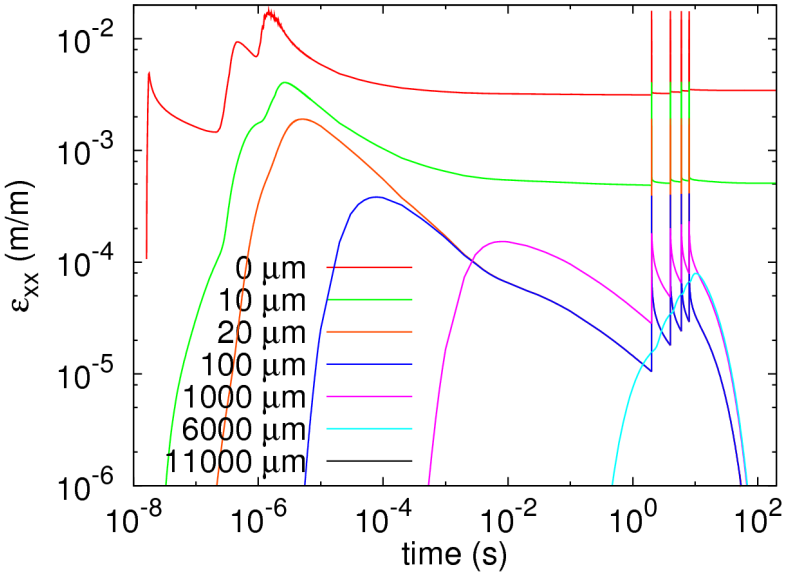
First wall melting avoided

Issues in first wall: stress and strain

Local increase of temperature ⟶ **material expansion**
Tangential compression-traction stresses due to geometrical restrictions.

Temporal evolution of tangential stress and longitudinal deformation in the first wall W (1mm)- SS316 (1cm).



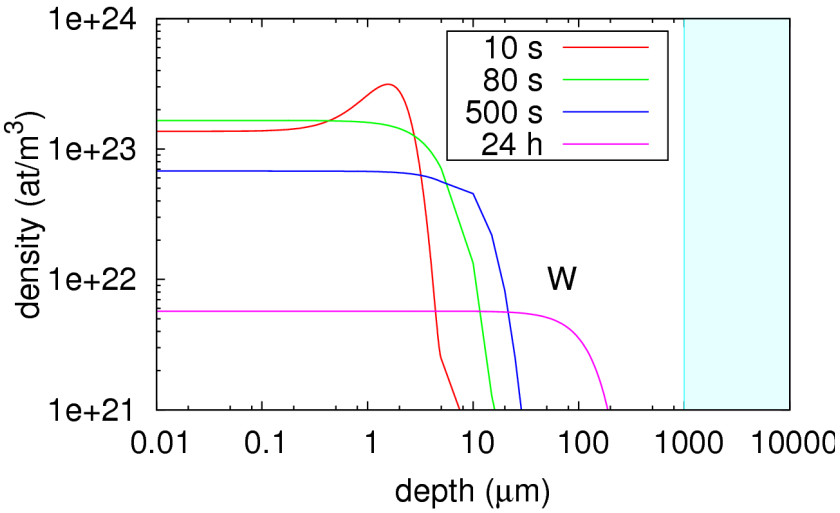


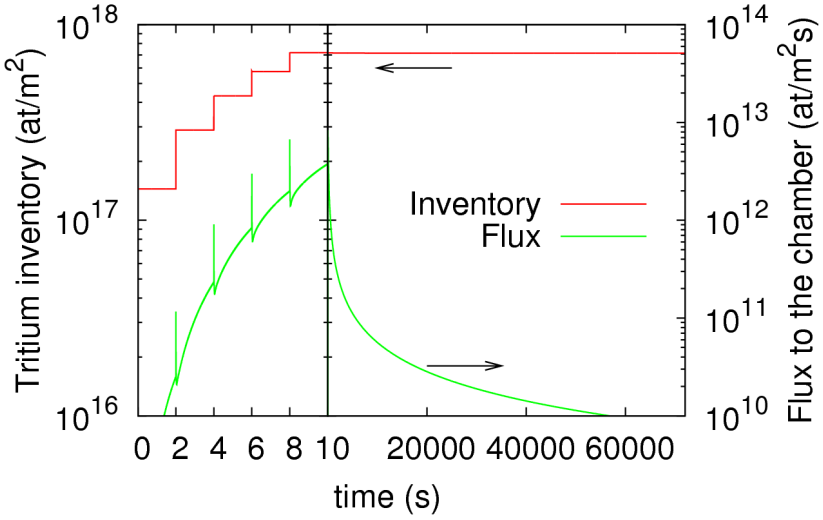
W plastically deforms depth < 20 μm, suffering compression-traction cycles.

Issues in the first wall: light species

TMAP7 software is used to estimates diffusion of light species implanted in first wall.

Bulk diffusion and surface reactions, control the amount of tritium returned to chamber in HiPER 4a conditions. Figures for tritium diffusion in first wall, W (1mm) – SS316 (1cm).



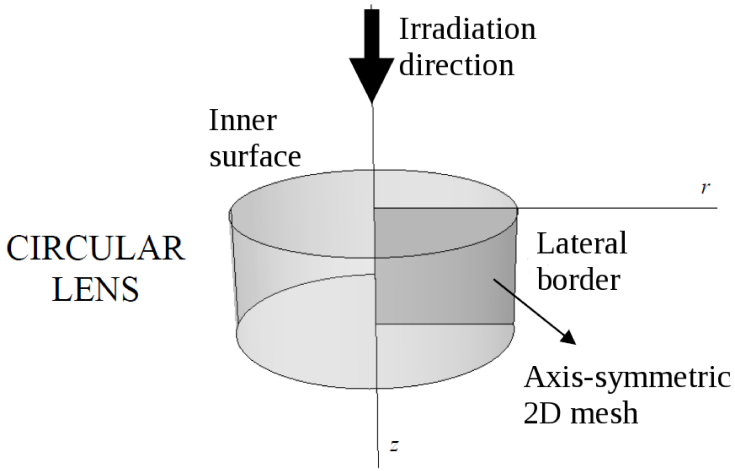


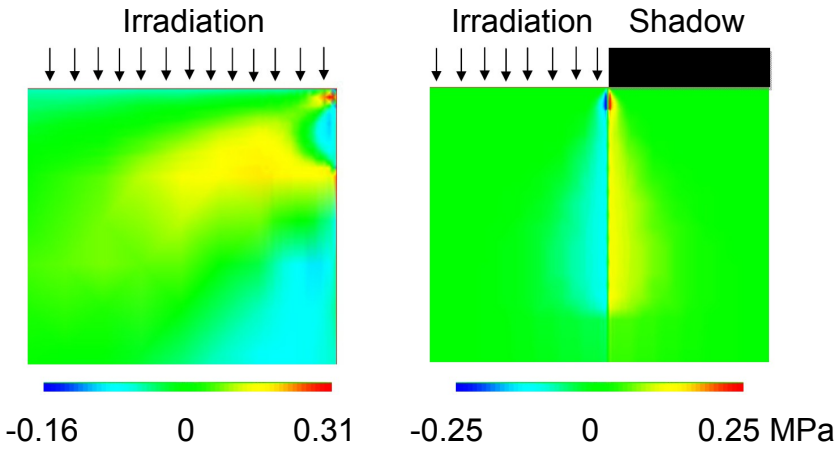
For reactor design, it is needed to implement other implanted species and tramps (vacancies and He bubbles) in the model.

Issues in lens

Silica lenses are located at 8 meters from the center of the chamber

Heat diffusion has been studied with 2D model.





Deflection of ions is mandatory to avoid melting. X-rays can be supported, only located stress.

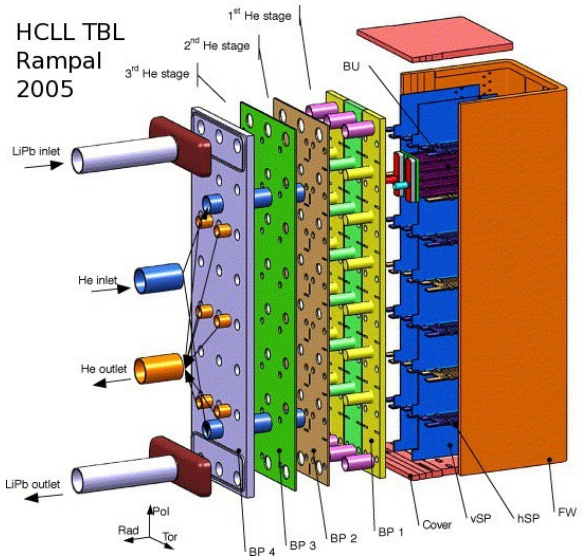
Issues in structural and coolant

Diffusion issues located in the area of the structural and coolant

Thermal gradients due to geometry and different materials

Formation of H_2 and He in structural due to nuclear reactions.

Close design with structural, coolant and blanket



Breeder blanket concept for ITER (Rampal 2005)

Mass diffusion restrictions due to geometry, materials and junctions

Atomistic defects in structural modify metal properties and aid tritium retention

Tritium can be mixed with coolant (He)

Issues in blanket

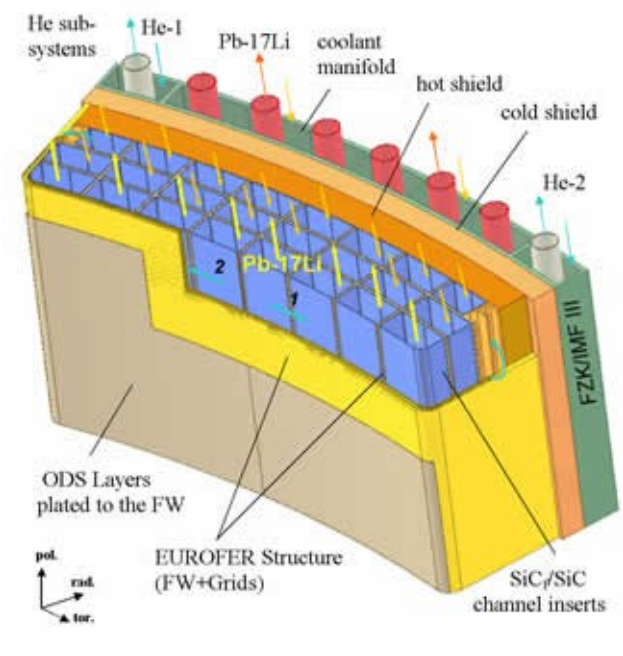
Diffusion issues located in the area of the blanket

Tritium production

$$n + {}^{7}Li \rightarrow {}^{4}He + {}^{3}T + n$$

$$n + {}^{6}Li \rightarrow {}^{4}He + {}^{3}T$$

Heat and mass diffusion in a liquid breeder blanket with motion



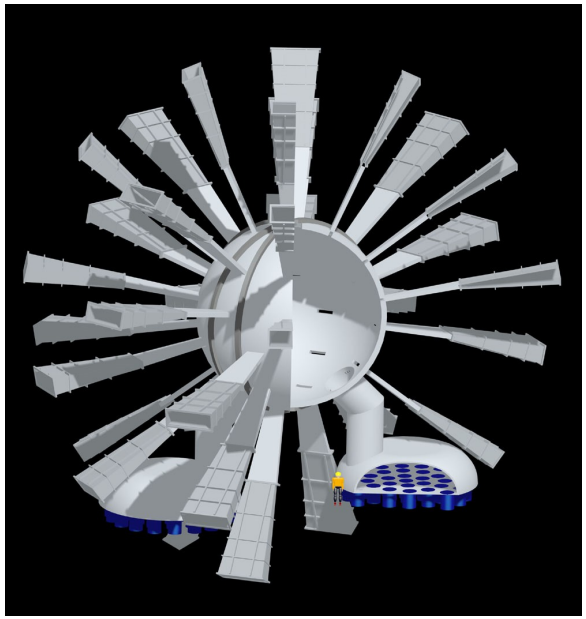
Breeder blanket concept for ITER (KIT/IMF III)

Tritium diffusion and recuperation from the breeder (He bubbles)

Diffusion restriction due to corrosion of the wall in contact with Li or LiPb

Estimation and localization of retained tritium

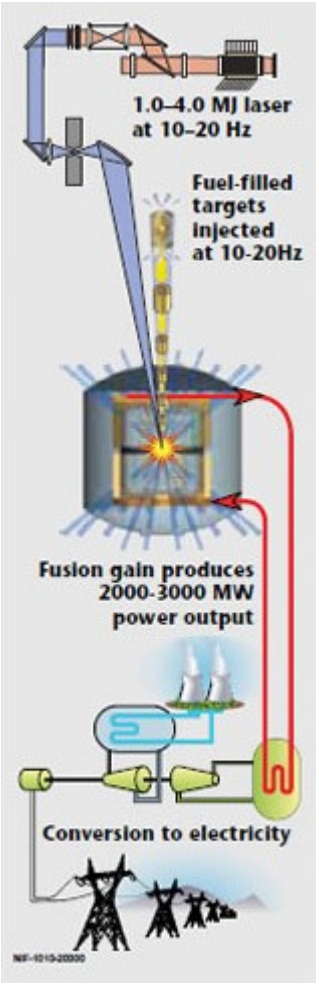
Another issues



HAPL vacuum pumps

Vacuum chamber
- Vacuum pump
- Tritium recycling

Thermodynamical cycle



NIF concept

It is important to know potential common heat an mass diffusion issues in magnetic and inertial fusion reactors

Conclusions

- There are **several heat and mass diffusion problems** which affect to the IFC chamber design.

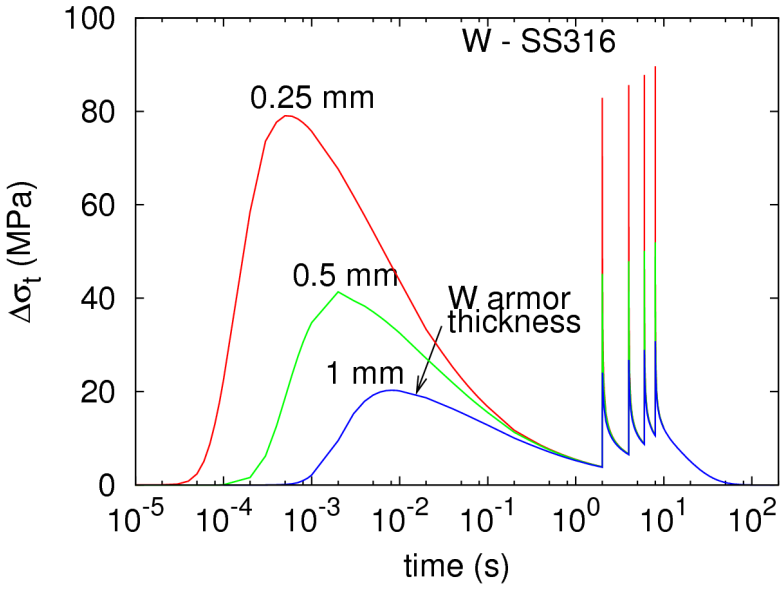
- **New simulation models and experiments** are needed to take into account the extreme conditions due to ignition pulses and neutron flux.

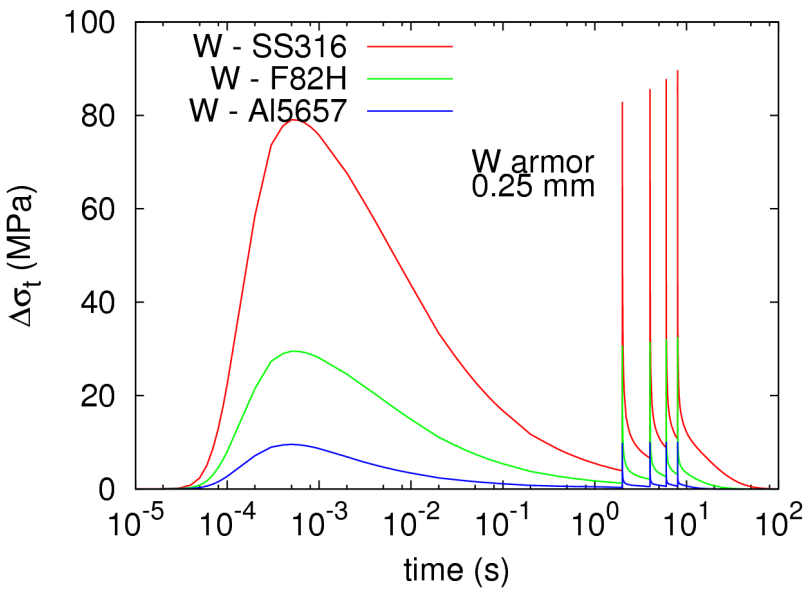
Diffusion Issues of Heat and Light Species in Laser Fusion Devices

Thank you for your attention

Issues in first wall: junction interface

Because of the **different expansion coefficients**, W and structural, there is a discontinuity in the tangential stress ($\Delta\sigma_t$)



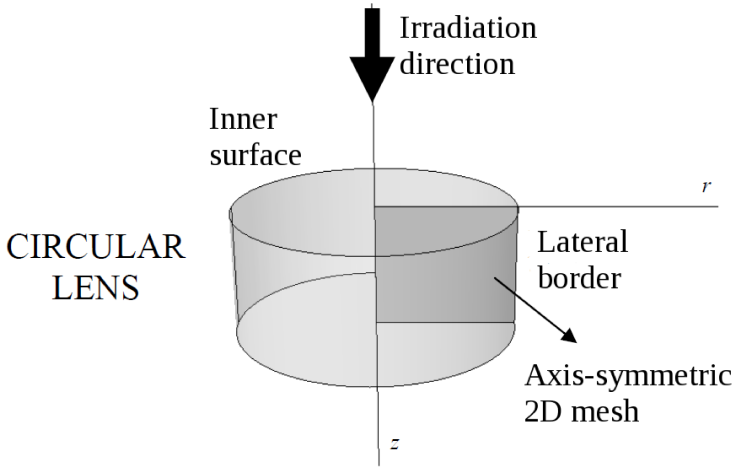


$\Delta\sigma_t$ decreases by selecting structural material with:
lower expansion coefficient (F82H) and high thermal conductivity (Al5657).

Issues in lens

Silica lenses located at 8 meters from the center of the chamber

Deflection of ions is mandatory to avoid melting. X-rays can be supported, only located stress.



Accumulation of atomistic defects increases the absorption. At high temperatures, annealing reduce defects.